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Search for SUSY in final states with jets and two same charge or three leptons with ATLAS detector

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Supersymmetry (SUSY) is a theoretically favoured candidate for physics beyond the Standard Model (SM). Many Supersymmetric models predict squarks ($\tilde{q}$) and gluinos ($\tilde{g}$) that could be accessible at the LHC, due to the large cross sections. In SUSY theories squarks and gluinos decay in cascades producing SM particles and lighter SUSY particles. When R-parity is conserved, the Lightest Supersymmetric Particle (LSP) is stable and weakly interacting, so supposed to be undetected and producing missing transverse momentum ($\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$) in the final state. This proceeding summarizes the results in the search for squarks and gluinos in final state with jets, $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$, and two same sign or three leptons during the Run1 at $\sqrt{s} = 8$ TeV.

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1. Introduction and Motivation

Supersymmetry (SUSY) is one of the most studied theories to extend the Standard Model (SM) beyond the electroweak scale. If R-parity is conserved, SUSY particles are produced in pairs and the lightest supersymmetric particle (LSP) which is typically the lightest neutralino $\tilde{\chi}_1^0$ is stable. In many models the LSP can be a suitable candidate for dark matter. If the masses of the supersymmetric particles are at the TeV-scale, it also provides a possible solution for the hierarchy problem in the Standard Model. A search for supersymmetric phenomena in final states with two leptons (electrons or muons) of the same electric charge or three leptons, jets and missing transverse energy E_T^{miss} with proton-proton collision at $\sqrt{s}$=8 TeV[1] collected by ATLAS[2] at LHC is presented . The analysed data-sample corresponds to an integrated luminosity of $20.3fb{-}1$ and has been collected in 2012.

While the same-sign leptons signature is present in many supersymmetric scenarios, SM processes leading to such events have very small cross-sections. Therefore, this analysis benefits from a small SM background in the signal regions leading to a good sensitivity especially in compressed regions of the SUSY phase-space. Except from the prompt production of same-sign lepton pairs, the main sources for SM processes contaminate the signal regions are fake-leptons and leptons with a change mis-identification. This allows to use relatively loose kinematic requirements on E_T^{miss} increasing the sensitivity to scenarios with small mass differences between SUSY particles (compressed scenarios) or where R-parity is violated.

2. Signatures with strong production

This analysis is sensitive to a wide range of SUSY models which give a same sign (SS) or 3 leptons (3L) final state. Gluinos produced in pairs or in association with a squark can lead to SS signatures when decaying to any final state that includes leptons. Squarks can give a SS or 3L final states when produced directly in pairs or through $\tilde{g}\tilde{g}$ or $\tilde{g}\tilde{q}$ production with subsequent $\tilde{g} \to q\tilde{q}$ decay. Then the squarks decay in cascades involving top quarks (t), charginos, neutralinos or sleptons, which subsequently can decay in other particles and sparticles. Figure 1 shows the models to which this analysis is aiming, the Signal Regions are designed to focus on these models.

3. Signal Regions

The Signal Regions are defined after an optimisation study based on simulated events for the signal models proposed. Data is divided in two orthogonal samples: SS and 3L. In the first case the two leading isolated leptons must have same charge sign and p_T>[20,15] GeV and an additional veto on a third lepton with p_T>15 GeV is applied. While for the 3L samples are selected events where the three highest-pT leptons must have a $p_T >$ [10,15,15] GeV and no requirement is present on the electric charge.

Different kinematic variables are used to define 5 non-overlapping Signal Regions: E_T^{miss}, jet and b-jet multiplicities (N_{jet} and N_{b-jets}), effective mass m_{eff} computed from all signal leptons and selected jets as $m_{eff} = E_T^{miss} + \sum p_T^l + \sum p_T^{jet}$, transverse mass m_T computed with the highest-p_T lepton (l1) and E_T^{miss} as $m_T = \sqrt{2p_T^{l1}E_T miss(1-cos[\Delta\phi(l1, p_T^{miss})])}$ and the invariant mass m_{ll}

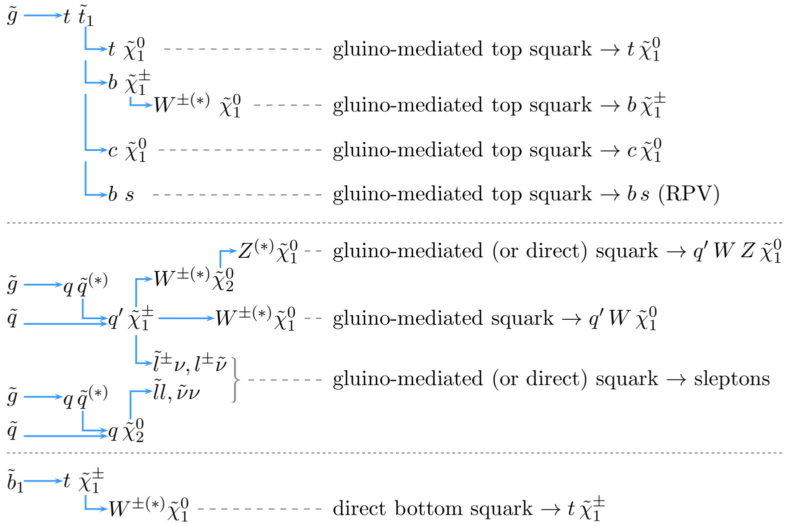


Figure 1: Overview of the SUSY processes considered in the analysis. The initial supersymmetric particles are always produced in pairs: $pp \to \tilde{g}\tilde{g}$, $\tilde{b}\bar{\tilde{b}}$ or $\tilde{q}\bar{\tilde{q}}$. The notation q ($\tilde{q}$) refers to quark (squark) of the first or second generation. The slepton and sneutrino decay as $\tilde{l} \to l\tilde{\chi}_1^0$ and $\nu \to \nu\tilde{\chi}_1^0$, respectively. Leptons in the final state can arise from the decay of any W or Z bosons or sleptons that are produced. The charge-conjugate processes are also considered.

computed with opposite-charge leptons.
Figure 2 shows the definition for the 5 SR, each of them is motivated by a different SUSY scenario: the SR3b signal region targets gluino-mediated top squark scenarios resulting in signatures with four b-quarks; the SR0b signal region is sensitive to gluino-mediated and directly produced squarks of the first and second generations, which do not enhance the production of b-quarks; SR1b targets third-generation squark models resulting in signatures with two b-quarks; and finally the 3L targets scenarios where squarks decay in multi-step cascades.

SR	Leptons	$N_{b-\text{jets}}$	Other variables	Additional requirement on m_{eff}
SR3b	SS or 3L	≥ 3	$N_{\text{jets}} \geq 5$	m_{eff}>350 GeV
SR0b	SS	$= 0$	$N_{\text{jets}} \geq 3$, E_T^{miss}> 150 GeV, m_T> 100 GeV	m_{eff}>400 GeV
SR1b	SS	≥ 1	$N_{\text{jets}} \geq 3$, E_T^{miss}> 150 GeV, m_T>100 GeV, SR3b veto	m_{eff}>700 GeV
SR3Llow	3L	-	$N_{\text{jets}} \geq 4$, $50 < E_T^{\text{miss}} < 150$ GeV, Z boson veto, SR3b veto	m_{eff}>400 GeV
SR3Lhigh	3L	-	$N_{\text{jets}} \geq 4$, E_T^{miss}> 150 GeV, SR3b veto	m_{eff}>400 GeV

Figure 2: Definition of the signal regions.

4. Background estimation

Searches in SS and 3L are characterized by low background yields. There are three different sources of background: (1) prompt multi-leptons, (2) "fake" leptons, when hadrons are misidentified as leptons or are coming from heavy-flavour decays, and (3) charge mis-measured leptons from photon conversion, this background is negligible for muons.

4.1 Prompt lepton background

Standard Model processes with same-sign leptons or three leptons in the final states have a small cross section. The prompt leptons background in the Signal Regions requiring at least one b-jet (SR1b,SR3b) is mainly composed by W or Z bosons, decaying leptonically, produced in association with a top-antitop quark pair where at least one of the top decays leptonically. The main sources of background in Signal Regions with a b-jet veto (SR0b3j,SR0b5j) are diboson processes (WZ,ZZ,$W^{\pm}W^{\pm}$) produced in association with jets.
Other rare sources of background are $t\bar{t}H$, single top quark plus Z boson, $t\bar{t}t\bar{t}$ and VVV+jets.
All processes have a low cross-section and are estimated from Monte Carlo samples normalised to NLO calculations. Figure 3 reports the distributions of the m_{eff} in the Validation Regions for $t\bar{t}Z$ (left) and Diboson (right) processes: good agreement between MC expectation and data is observed.

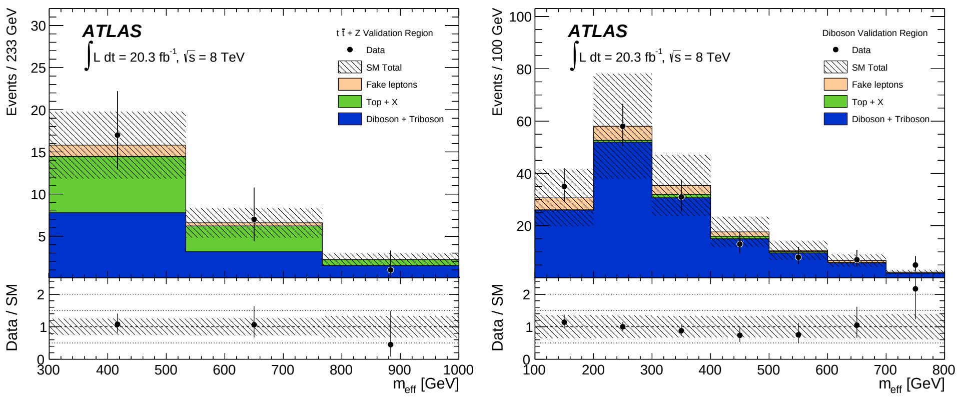


Figure 3: Left: Effective mass (m_{eff}) distributions for the $t\bar{t}Z$ Validation Region. Right: Effective mass (m_{eff}) distributions for the WZ+jets Validation Region. The statistical and systematic uncertainties on the background prediction are included in the uncertainty band. The last bin includes overflows. The lower part of the figure shows the ratio of data to the background prediction.

4.2 Fake lepton background

The fake lepton background is produced by processes where hadrons are mis-identified as leptons, or leptons are originating from heavy-flavour decays and electrons from photon conversion. The contribution in each Signal Region is estimated from data with a matrix-method, Figure 4 shows the distributions of the p_T of the leading lepton (left) and the transverse mass m_T for a eμ couple with 0 b-jets.

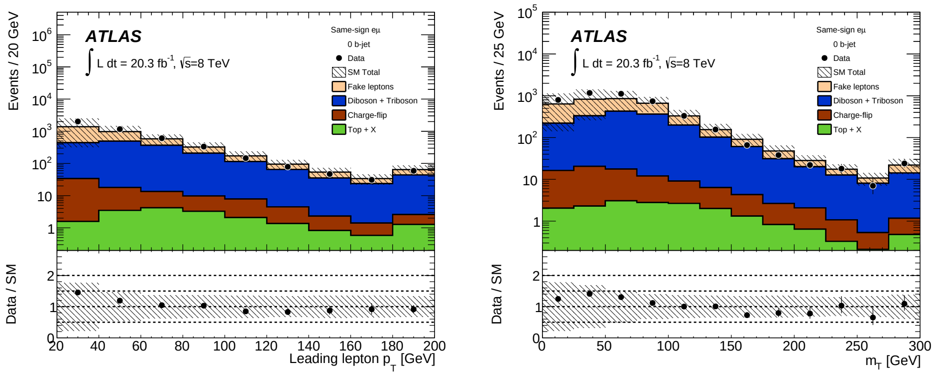


Figure 4: Left: Distribution of leading lepton p_T for events with no b-jet and eμ couple in the SS Validation Region. Right: Distribution of the transverse mass m_T for events with no b-jet and eμ couple in the SS Validation Region.

4.3 Charge mis-measurement background

The most relevant background for Same Sign signal regions is the mis-measurement of the charge of a lepton in a process with two opposite-sign leptons in the final state. Charge mis-identification is mainly due to the radiation of a hard photon from an electron followed by a conversion in e^+e^- pair in the material, where the electron with the opposite charge has the larger p_T. The charge-flip background is dominated by dilepton $t\bar{t}$ events and is significant only for electrons pair. The probability of mis-identifying the charge of a muon is determined in simulation to be negligible in the kinematic range relevant to this analysis.
This kind of background is estimated with a data-driven likelihood method analysing the number of same-sign and opposite-sign electrons couple in the mass range of the Z ([75-100] GeV). Figure 5 reports the distributions of E_T^{miss} (left) and Number of jets with $p_T > 40$GeV (right) for a SS couple of electrons: the charge-flip background is, as expected, dominant.

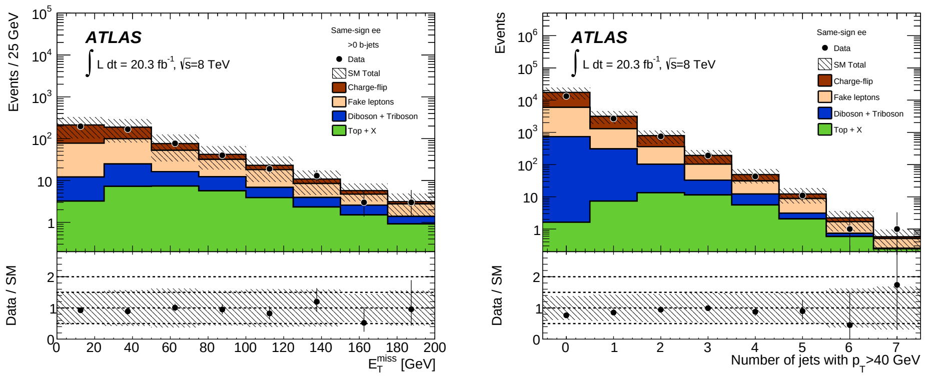
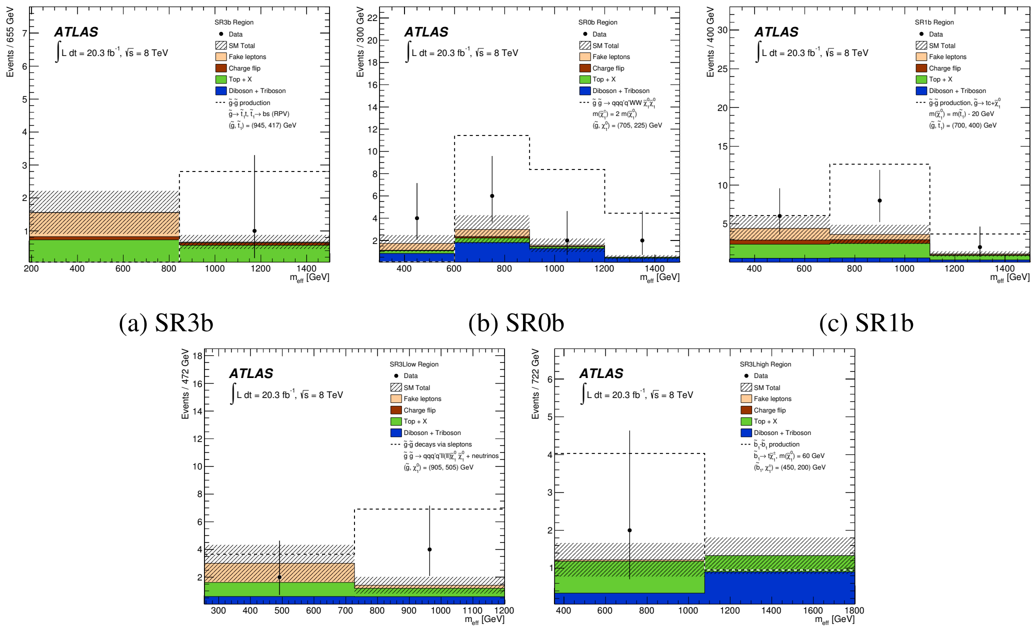


Figure 5: Left: Distribution of E_T^{miss} for the *ee* channel validation regions for events with at least one b-jet. Right: Distribution of number of jets for the *ee* channel validation regions.

5. Results and Interpretations

Figure 6 shows the effective mass distribution of the observed data events and SM predictions for the five signal regions: SR3b (a), SR0b(b), SR1b(c), SR3Llow(d) and SR3Lhigh(e). The distributions are for events passing all selections except the one on m_{eff}. No significant excess of events over the SM expectations is observed in any signal region, so an upper limit on the number of Beyond Standard Model events for each signal region can be set.



(a) SR3b (b) SR0b (c) SR1b

(d) SR3Llow (e) (SR3Lhigh

Figure 6: Effective mass (m_{eff}) distributions in the signal regions SR3b, SR0b, SR1b, SR3Llow and SR3Lhigh, used as input for the exclusion fits. The statistical and systematic uncertainties on the background prediction are included in the uncertainty band. The last bin includes overflows. Signal expectations from SUSY models of particular sensitivity in each signal region are shown for illustration.

5.1 Model-independent upper limits

Upper limits at 95% CL on the number of beyond the SM (BSM) events for each signal region are derived using the CL_s prescription[3]. The number of events can be normalised by the integrated luminosity of the data sample and then interpreted as upper limits on the number of events in SR originating from any BSM process. The visible BSM cross-section (σ_{vis}) is defined as the product of acceptance, reconstruction efficiency and production cross section. Any model which predicts an higher cross-section can be excluded.

The results are given in table 1, where $< \sigma_{vis} >^{95}_{obs}$ is the 95% CL upper limits on the visible cross section, and S^{95}_{obs} and S^{95}_{obs} are the observed and expected 95% CL upper limits on the number of BSM events.

Signal channel	$< \sigma_{vis} >^{95}_{obs}$ [fb]	S^{95}_{obs}	S^{95}_{obs}
SR3b	0.19	3.9	$4.4^{+1.7}_{-0.6}$
SR0b	0.80	16.3	$8.9^{+3.6}_{-2.0}$
SR1b	0.65	13.3	$8.0^{+3.3}_{-2.0}$
SR3Llow	0.42	8.6	$7.2^{+2.9}_{-1.3}$
SR3Lhigh	0.23	4.6	$5.0^{+1.6}_{-1.1}$

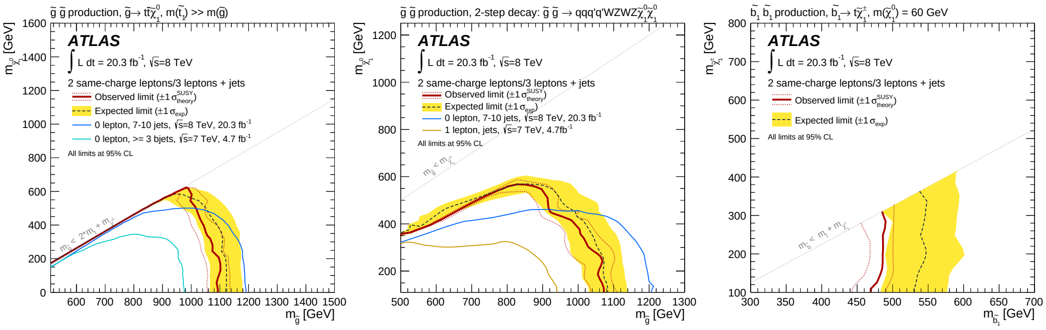
Table 1: The 95% CL upper limits on the visible cross section ($< \sigma_{vis} >^{95}_{obs}$), defined as the product of acceptance, reconstruction efficiency and production cross section, and the observed and expected 95% CL upper limits on the number of BSM events (S^{95}_{obs} and S^{95}_{obs}). Results are obtained with pseudo-experiments.

5.2 Model dependent limits

Starting from the signal models studied, an exclusion limit can be set for each one of them. The limits are calculated from asymptotic formulae with a simultaneous fit to all signal regions based on the profile likelihood method. To do so, the m_{eff} requirements are relaxed in each signal region and the fits inputs are the binned m_{eff} distributions.
The exclusion fits are tipically presented with a solid red line for the observed limit and a dashed grey line for the expected limit; in addition, two dashed red line represent the observed limits obtained by changing the SUSY cross section by one standard deviation ($\pm\sigma^{SUSY}_{Theory}$). Statistical and systematic uncertainties (theoretical SUSY cross section uncertainty not included) are shown by a yellow band ($\pm\sigma$) around the expected limit.
All models can be categorised in 3 simplified models which are used to design the Signal Regions and interpret the results. In Figure 7 are shown limit plots for a signal model related to each one of the 3 categories: gluino-mediated top squark (a), gluino-mediated (or direct) first- and second-generation squark (b), and direct bottom squark production (c).

6. Conclusions

A search for supersymmetry in multi-jets events with exactly two same-sign leptons or at least three leptons with proton-proton collision at $\sqrt{s}$=8 TeV collected by ATLAS at LHC has been presented. The analysed data-sample corresponds to an integrated luminosity of $20.3 fb-1$ and has been collected in 2012. The analysis has an interesting signature which provides a low SM background and is really sensitive to New Physics, in particular in compressed scenarios and RPV models.
No excess has been observed in data, and exclusion limits have been set to different SUSY scenarios. Gluino-mediated top squark scenarios are excluded for $m_{\tilde{g}}$< [600-1000] GeV. Similar limits are placed on gluino-mediated production of first and second-generation quarks for $m_{\tilde{\chi}^0_1}$ < [300-600] GeV. Limits are also placed on pair-production of bottom squarks and squarks of the first and second generations decaying in long cascades.



(a) (b) (c)

Figure 7: (a) Observed and expected exclusion limits on gluino-mediated top squark production, obtained with 20.3 fb^{-1} of pp collisions at $\sqrt{s}$=8 TeV. Results are compared with the limits obtained by previous ATLAS searches[4, 5]. (b) Observed and expected exclusion limits on gluino-mediated production of first- and second-generation squarks, obtained with 20.3 fb^{-1} of pp collisions at $\sqrt{s}$=8 TeV. Results are compared with the limits obtained by previous ATLAS searches[5, 6]. (c) Observed and expected exclusion limits on direct bottom squark production, obtained with 20.3 fb^{-1} of pp collisions at $\sqrt{s}$=8 TeV, for $b \to t\tilde{\chi}_1^{\pm}$ decays with $m_{\tilde{\chi}_1^0}$=60 GeV.

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